PATENT

Attorney Docket: 00-268

"EXPRESS MAIL" MAILING
LABEL NUMBER EL643644021US
DATE OF DEPOSIT 8-2-00
I HEREBY CERTIFY THAT THIS PAPER OR FEE IS BEING DEPOSITED WITH THE UNITED STATES POSTAL SERVICE "EXPRESS MAIL POST OFFICE TO ADDRESSEE" SERVICE UNDER 37 C.F.R. §1.10 ON THE DATE INDICATED ABOVE AND IS ADDRESSED TO THE ASSISTANT COMMISSIONER FOR PATENTS, WASHINGTON, D.C. 20231

Wendy Taylor
[NAME OF PARALEGAL]

Adaptive Antenna Method and Apparatus

By:

Brian Banister
10354 Moselle Street
San Diego, CA
Citizenship: U.S.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to digital wireless communications and more specifically to methods and apparatus pertaining to an adaptive antennae weighting scheme.

Description of the Related Art

Digital wireless systems presently being deployed are commonly seen to be forward link (base station ("BS") to mobile station ("MS")) capacity limited. This is due mostly to asymmetric traffic: most data applications, such as web browsing, are envisioned to be sending data to the mobile user on the forward link, while the reverse link might contain only small control packets, i.e. a new IP address to download, so that the forward data rate is much greater than the reverse data rate.

Forward capacity can be increased with an array of antennae in a base station whose individual carrier amplitudes and phases can be adjusted based on feedback from a MS. In particular, a TxAA algorithm will typically transmit the same MS-specific waveform on multiple antennae, applying adaptive complex weights to the baseband signal applied to each antenna. To allow the MS to do coherent demodulation, a dedicated pilot channel will typically be transmitted in the same manner as the data.

While RxAA algorithms at the BS are fairly straight forward, TxAA algorithms are not. The mere definition of an "optimal" TxAA algorithm is not unambiguous as the optimization of one mobile's forward link can degrade another's, leading to complex tradeoffs which are not part of the RxAA problem.

Most TxAA algorithms will require some knowledge of the transmission channel from the BS to the MS. Given this knowledge and a defined "optimality" criterion, the BS can determine the TxAA weights. The difficulty here is that the MS can measure the channel, but it is the BS which needs this information to adjust its transmit weights. Also, there can be some additional complexity in that the mobile which must generally measure the channel of each transmit antenna separately, in addition to measuring the channel of the overall Tx weight adjusted signal, the latter being required for the demodulation of the signal.

Presently, there are a number of proposed methods for implementing TxAA. According to some of these proposals, a few bits are allocated to the MS to encode the channel gain and phase. See Thomas Derryberry, Balaji Raghothaman (Nokia) "Transmit Adaptive Arrays without User Specific Pilot", document # C30-19990817-030, submitted to 3GPP2 August 1999; Mark Harrison (Motorola) "Tx AA Parameter Recommendations", document #C30-19990914-010, submitted to 3GPP2, Tokyo Japan, September 1999; and Mark Harrison, Kiran Kuchi (Motorola) "Open and closed loop transmit diversity at high data rates on 2 and 4 elements", document #C30-19990817-17, submitted to 3GPP2 August 1999. These methods do not allow the desired antenna weights to be precisely determined

because the channel state must be distorted in order to be fed back to the BS with a low bit rate.

The academic literature has typically assumed that the full channel information is available at the transmitter, which is not a practical assumption. See, e.g. Jen-Wei Liang, Arogyaswami Paulraj "Forward link antenna diversity using feedback for indoor communication systems" Proceedings, 1995 International Conference on Acoustics, Speech, and Signal Processing, May 1995; Farrokh Rashid-Farrokhi, K.J. Ray Liu, Leandros Tassiulas "Transmit beamforming and power control for cellular wireless systems" IEEE Journal on Selected Areas in Communications, Vol. 16, No. 8, October 1998. There have been several submissions to the TIA standardization body for TxAA algorithms with channel feedback from MS to BS, some of which are referenced above. All of these submissions require the mobile to measure a primary and secondary pilot transmitted from the primary and secondary antennae. Some submissions have shown that 4 antenna transmission can give better performance, with no recognition of the increased complexity at the MS.

The use of a few bits of channel feedback leads to substantial degradation relative to the possible performance, since the feedback requires low bit rate quantization. Also, the mobile must individually measure and transmit information for each antenna; the MS requires extra hardware to perform these functions. Furthermore, the above described methods do not gracefully grow to more antennae.

The above mentioned systems are illustrated inFigure 1, Figure 2 and Figure 3, which illustrate a CDMA system. Figure 1 shows a transmitter 10 with two antennae, first antenna 12 and second antenna 14. As is shown, different common pilot signals are associated with different antennae. For each user, such as user 0 and user 1, the transmitter 10 includes an adder, 16 and 18 respectively, that adds together a dedicated pilot signal for the user and the forward traffic for that user. Multipliers 20 and 22 multiply the summed signal with complex weights for the first and second antennae 12 and 14, respectively. For each antenna, the weighted user signals are summed by adders 24 and 26 and the result is added by adders 28 and 30 to the pilot signal for that antenna. (It should be noted thatFigure 1 represents a complex baseband equivalent, as no RF modulation stage is shown.)

Figure 2 and Figure 3 show possible embodiments for receivers that may be used to receive signals transmitted by the transmitter 10. As shown inFigure 2, a received signal is divided into three components: one signal corresponding to the dedicated channel, one signal corresponding to the common pilot for the first antenna and one signal corresponding to the common pilot for the second antenna. This division is accomplished by multipliers 32, 34 and 36 and accumulators 38, 40 and 42. A more hardware efficient way is shown in Figure 3, which employs multiplexer 44 and demultiplexer 46 to alternately select between the signals for the different transmit antennae. This time multiplexed processing saves hardware at the expense of 3dB loss of precision for each channel, which is acceptable given

the low bit rate, low precision channel reporting used by the mobile to report these channel estimates to the BS.

The channel estimate the mobile attains is coded into some low bit representation. The bit rates mentioned in the above cited references are 1,2 or 4 bits (1b phase, 2b phase, or 3b phase + 1b amplitude). So, for a forward channel vector $\mathbf{c}$, the mobile generates the estimate $\hat{\mathbf{c}}$, which is then quantized to give the feedback estimate $\hat{\hat{\mathbf{c}}}$.

Note that the MS channel estimation hardware ofFigure 2 or Figure 3 can be used for an arbitrarily large number of Tx antennae, as long as there are unique pilot codes for each antenna and MS knows all of these codes.

Finally, the proposed systems have the MS report the channel estimate based on 1 "path". In the presence of resolvable multi-path due to delayed reflections of the transmitted waveform, particularly for CDMA, there may be more than one path usable to the MS. In order to report the channel for N such paths, the MS to BS feedback rate would have to increase N-fold, and the number of such paths would somehow have to be communicated to the BS. This is not practical, and instead the MS reports the channel estimate for only the strongest path. This discards some useful channel characteristics which could further increase performance under these circumstances.

The algorithm employed by the BS to utilize the received channel information would most likely be a simple matched transmission weighting. That is, the forward weights chosen would be the conjugate of the forward vector channel, so that the weights are

$$\mathbf{w} = \hat{\mathbf{c}}^*$$

This formulation maximizes the signal power to the mobile without regard to the locations of the other mobiles. It does not steer nulls to the other mobiles. The channel estimate from a given mobile could be used to determine transmission nulls of the other mobiles, but the coarseness of the channel estimate (no more than 4 bits) makes this ineffective.

To summarize, schemes such as that shown inFigure 1, Figure 2 and Figure 3 have significant drawbacks. In particular, as previously mentioned, the use of a few bits of channel feedback requires quantization which leads to substantial degradation relative to the possible performance. Also, since an MS unit must individually measure and transmit information for each antenna; the MS requires extra hardware to perform these functions. Furthermore, the above described methods do not gracefully grow to more antennae.

SUMMARY OF THE INVENTION

According to the present invention, a transmitter includes hardware and/or software for adaptively updating weights for a plurality of antennae. In particular, according to the present invention, the transmitter generates a pair of test weight vectors, each vector comprised of a plurality of complex entries, with each entry corresponding a different one of a plurality of antennae. Preferably, the first complex weight vector is equal to $\frac{\mathbf{w}_{base}+\beta\cdot\mathbf{v}}{\|\mathbf{w}_{base}+\beta\cdot\mathbf{v}\|}$ and the second complex weight vector is equal to $\frac{\mathbf{w}_{base}-\beta\cdot\mathbf{v}}{\|\mathbf{w}_{base}-\beta\cdot\mathbf{v}\|}$, where **v** is a test perturbation vector comprised of a plurality of complex entries, with each entry corresponding to a different one of a plurality of antennae, β is an algorithm constant and $\mathbf{w}_{base}$ is a vector that is updated based on feedback received from a receiver, as will be further described below. The first and second complex weight vectors are applied to a dedicated pilot signal during alternate time intervals. During each time interval, the average of the first and second complex weight vectors is applied to the data traffic transmitted by the transmitter.

A receiver (e.g. a mobile station) alternately receives the pilot signal as multiplied by the first and second weight vectors as described above. The mobile determines which of the weighted pilot signals resulted in a stronger signal received at the mobile and, based upon this determination, transmits feedback. The transmitter receives the feedback and updates the first and second weights accordingly. In particular, if the first weight resulted in a stronger signal, $\mathbf{w}_{base}$ is

updated to become $\frac{\mathbf{w}_{base} + \beta \cdot \mathbf{v}}{\|\mathbf{w}_{base} + \beta \cdot \mathbf{v}\|}$ (the previous first weight) whereas if the second weight resulted in a stronger signal, **w** is updated to become $\frac{\mathbf{w}_{base} - \beta \cdot \mathbf{v}}{\|\mathbf{w}_{base} - \beta \cdot \mathbf{v}\|}$ (the previous second weight). The above described process is repeated with the new $\mathbf{w}_{\text{base}}$. New test vectors **v** are generated and applied after each MS channel measurement is made.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the accompanying drawings in which:

Figure 1 is a block diagram of one type of a conventional two antenna transmitter that employs antenna weighting derived from receiver feedback

Figure 2 is a block diagram of one type of conventional receiver that estimates the channel for each transmit antenna individually.

Figure 3 is a block diagram of an alternate type of conventional receiver that estimates the channel for each transmit antenna individually.

Figure 4 is a block diagram of an embodiment of a transmitter constructed according to the present invention.

Figure 5 is a block diagram of an embodiment of a receiver constructed according to the present invention.

Figure 6 is a block diagram of a preferred embodiment of a receiver constructed according to the present invention.

Figure 7 is a flow chart that outlines pertinent features of the operation of the transmitter shown in Figure 4.

Figure 8 is a flow chart that outlines pertinent features of the operation of the receiver shown in Figure 5.

Figure 9 is a flow chart that outlines pertinent features of the operation of the receiver shown in Figure 6.

Figure 10 is a timing diagram that shows a preferred timeline for weight adjustment, channel measurement and feedback.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

Figures showing transmission and receive systems omit portions of the radio for convenience (quadrature modulation/demodulation). Those portions of the radio not shown are not relevant to the invention. Signals are represented as complex baseband equivalents, and all arithmetic is complex.

DETAILED DESCRIPTION OF THE INVENTION

Nomenclature

AA	adaptive antenna, more generally adaptive antenna algorithm
BS	base station, fixed station which communicates with multiple mobile stations and provides their gateway to the fixed network.
CDMA	code division multiple access
DS-CDMA	direct sequence CDMA
forward link	radio link from the transmitting base station to the receiving mobile station
HW	hardware, referring to the fixed digital logic portion of a modem as opposed to SW
MS	mobile station, a user of the cellular network, e.g. a cell phone or a wireless data terminal
pilot	a know signal or "training sequence" transmitted so that the receiver may use it to estimate the channel response.
reverse link	radio link from the transmitting mobile station to the receiving base station
Rx	receive
SW	software, typically to distinguish the (modifiable) SW portion of a modem from the HW
Tx	transmit

Embodiment

For clarity of representation, certain non-essential assumptions are made for this patent application. First, the system described is a DS-CDMA (Direct Sequence, Code Division Multiple Access) system using "pilots" for coherent demodulation. In fact, most modern digital wireless systems include a pilot (sometimes known as a "training sequence" when time multiplexed rather than code multiplexed) used for channel estimation, and any such system could use this invention.

Second, the below described adaptive array transmitter is considered to be a base station and the receiver is a mobile station. This applies to cellular communications. In fact, the mobile station may also have a transmit array operating in the same manner. Also, the system may not be cellular at all, but peer to peer communication such as Bluetooth.

The invention as described can be applied without regard to how many antennae the transmitting BS is using, and in particular the MS does not need to know how many antennae are being used.

Figure 4 is a block diagram of a BS transmitter 50 according to a possible embodiment of the present invention. For ease of illustration, two antennae, first antenna 52 and second antenna 54 are shown but it will be appreciated that the present invention may easily be scaled to any number of antennae. Also for ease of

illustration, BS hardware corresponding to one mobile unit is shown but the transmitter 50 will typically have analogous hardware for a number of other users.

As shown, the transmitter 50 comprises a plurality of multipliers 56, 58, 60, 62, 64 and 66, summers 72 and 74 and multiplexers 68 and 70. Multipliers 64 and 66 multiply a dedicated pilot signal and a forward traffic signal, respectively, with corresponding gains (real valued). Multipliers 60 and 62 multiply the forward traffic signal by different weights from the weight vector**w**, w_0 and w_1, where w_0 is the weight for the first antenna 52 and w_1 is the weight for the second antenna 54. The weight values will be discussed below. $w_{0,odd}$ and $w_{0,even}$, weights from the weight vectors $\mathbf{w}_{odd}$ and $\mathbf{w}_{even}$ respectively, are provided as inputs to the multiplexor 68, which alternates between them. Similarly, $w_{1,odd}$ and $w_{1,even}$ weights are provided as inputs to the multiplexer 70, which alternates between them. The weighted traffic and pilot signals are summed by the summers 72 and 74 and transmitted by the first antenna 52 and the second antenna 54 respectively. The mathematical representation of the waveform transmitted by the antennae 52 and 54 will be described below.

Figure 5 is a block diagram of a MS receiver 80 according to a possible embodiment of the present invention which shows the principle of the feedback decision made by the MS. The receiver 80 comprises an antenna 82, a multiplier 84, and an accumulator 86. The receiver 80 further comprises a demultiplexer 88, accumulators 90 and 92 and a summer 94, which are preferably implemented in software. Signals received over the antenna 82 are multiplied by a pilot

despreading code, as is well known in DS-CDMA systems, and the result passed to accumulator 86, which accumulates a symbol from the chips it receives. "Even" and "odd" channel estimates are alternately accumulated in accumulators 90 and 92. The even estimate and odd estimates (i.e. the estimates for the alternating even and odd time slots) are summed by summer 94 to generate a dedicated channel estimate (for coherent demodulation). Also, in decision block 94 the power of the even and odd estimates are compared and the value of a feedback bit is set depending upon which of the two estimates indicates a greater power. In other words, the receiver 80 determines the power of the received pilot in the odd and even time slots, and determines whether the power in the odd or the even slot was greater.

Figure 6 is a block diagram of a preferred embodiment of a receiver (e.g. an MS) 229 constructed according to this invention. This figure illustrates the efficient use of the pilot format to both aid antennae adaptation and to demodulate incoming data. The pilot is used to extract a preliminary channel estimate $\hat{c}$ using the multiplier 202 and the accumulator 204. A sliding window filter 212 maintains the data channel estimate $\hat{\hat{c}}$. The preliminary data symbol estimates are generated by multiplying the data despreading sequence with the received signal with multiplier 216 and accumulating the result in accumulator 218. These preliminary symbol estimates are then delayed in a deskew buffer 219 and then the data channel estimate $\hat{\hat{c}}$ is conjugated in conjugation unit 214 and multiplied with the preliminary data symbol estimates with multiplier 220 to generate the final data symbol estimates. A channel difference estimate is simultaneously maintained

through a separate data path. The preliminary channel estimate $\hat{c}$ is inverted for odd time and non-inverted for even time slots through the selection of multiplexer 206 and application of ±1 in multiplier 207, with this result accumulated in accumulator 208 to generate $\hat{c}_{diff}$. When the measurement interval is complete, even and odd channel estimates are extracted from $\hat{c}_{diff}$ and $\hat{\hat{c}}$ using adders 210 and 224. The more powerful channel estimate is then selected in decision block 228.

Note that in the case of resolvable multipath the mobile will be tracking several versions of the received pilot, making channel estimates for each one. In order to properly determine which Tx weight vector gives the best receive power, the mobile combines the channel estimate powers from each path prior to doing the decision comparison. Similarly, if the MS 229 has multiple antennae, the decision would be based on the sum of channel estimate powers over all antennae.

Note also that the same method can be applied to soft handoff, where multiple basestations may be transmitting the same data to the mobile with individually adjusted TxAA weight vectors. That is, the processing of the mobile can be applied to each BS individually, and the odd/even power summations used to determine the feedback bit would be the summation of the powers for each path and for each BS. All BS's would receive the same feedback bit and adjust accordingly. This is almost effectively considering the weight vector to be a concatenation of the individual BS weight vectors, but it must be noted that each BS would individually normalize its weight vector. The described method provides

a very simple manner for the TxAA to be distributed across several BS's with no increase in MS complexity.

The following describes in greater detail the operation of the transmitter 50 and receiver 229 described above.

Define the following

n	time index, at the nyquist rate (chip rate for DS-CDMA)
m	time index at decimated (slot) rate, $m = \lfloor n/N \rfloor$
K	number of users to which the BS is transmitting
N	duration of the pilot even/odd banking slot
M	number of slots between weight updates
u(n)	transmitted vector at time n, $[\mathbf{u}]_j$ is the i^{th} antenna.
w(n)	antenna complex weights for the specific MS described, data channel
$\mathbf{w}_{even}$(n)	antenna complex weights for the specific MS described, even pilot channel
$\mathbf{w}_{odd}$(n)	antenna complex weights for the specific MS described, odd pilot channel
x(n)	information bearing modulated signal for the specific MS described
p(n)	dedicated pilot for the specific MS described
$g_{,pilot/traffic}$	gain for the pilot/traffic channel for the specific MS described

The complex baseband representation of the transmitted waveform at the antenna, characterizing the amplitude and phase of the modulated radio carrier

transmitted by the antenna (such complex baseband representations are well known, see John Proakis, *Digital Communications*, 1995, Third Edition, McGraw-Hill Inc., New York, NY), is given as follows. The equation adds a subscript k differentiating the signals for the plural mobiles.

$$\mathbf{u}(n) = \sum_{k=0}^{K-1} \left(g_{k,traffic} \mathbf{w}_k(n) x_k(n) + g_{k,pilot} \left(\left(\lfloor n/N \rfloor \bmod 2 == 0 \right) \mathbf{w}_{k,even}(n) + \left(\lfloor n/N \rfloor \bmod 2 == 1 \right) \mathbf{w}_{k,odd}(n) \right) p_k(n) \right)$$

For conciseness of presentation, the following text focuses on the present invention's method from the point of view of a specific mobile with an arbitrary index k, and the subscript k is omitted.

In particular, the odd transmit weight is applied to the dedicated pilot on odd time slots and vice versa for the even weights. To ensure proper coherent demodulation, the even/odd weights are preferably constrained by the relation:

$$\mathbf{w}(n) = \frac{\mathbf{w}_{even}(n) + \mathbf{w}_{odd}(n)}{2}$$

It is worth noting that when the odd and even test weights are generated by the perturbation technique described below, then it is valid to consider that

$$\mathbf{w}_{base}(n) \cong \frac{\mathbf{w}_{even}(n) + \mathbf{w}_{odd}(n)}{2}$$

and hence one may in that case use $\mathbf{w}_{base}(n)$ as the weight vector applied to the data channel.

Figure 7 is a flow chart that outlines pertinent features of the operation of the transmitter 50. In block 100, a vector $\mathbf{w}_{\mathrm{base}}$ is initialized to an arbitrary vector with a unit norm. In block 102, a new test perturbation vector $\mathbf{v}(n)$ is generated. Each vector entry is a complex number and corresponds to one of the antennae 52 or 54; each such entry therefore corresponds to a test weight to be applied to the transmission of the pilot signal over a particular antenna. The test perturbation vector is preferably determined in a manner such that its entries appear mutually independent. As a point of reference, it is assumed that the expected value (or long term average over many realizations) of the magnitude squared of each entry of $\mathbf{v}$ is 2, so that $E\left(\|\mathbf{v}\|^2\right) = 2 \cdot (\text{number of antennae})$. In this way, the amplitude of the applied perturbation is encompassed in the algorithm parameter β, as described below. For example, $\mathbf{v}(n)$ could equal $[\pm1\pm j, \ldots \pm1\pm j]^T$ ($\mathbf{v}(n)$ would have just two entries for the example transmitter of Figure 4), where the +'s and –'s for the entries are randomly determined. However, the preferred $\mathbf{v}(n)$ is a complex Gaussian vector of uncorrelated entries with variance of 2.

In block 102 the current value of $\mathbf{v}$ is stored as $\mathbf{v}_{\mathrm{old}}$ and a new value is determined for $\mathbf{v}$. The old value is stored so that when the feedback is received at a later time (block 116) the transmitter 50 knows which perturbation vector the feedback corresponded to and can adapt accordingly. In block 104, even and odd

weights and data channel weights are updated based on the new value forv. This is summarized as follows.

when beginning of test interval

$$\mathbf{v}_{old} \Leftarrow \mathbf{v}$$

$$\mathbf{v} \Leftarrow \text{normalized test perturbation vector, new value every NM time indices}$$

$$\mathbf{w}_{even} \Leftarrow \frac{\mathbf{w}_{base} + \beta \cdot \mathbf{v}}{\|\mathbf{w}_{base} + \beta \cdot \mathbf{v}\|}$$

$$\mathbf{w}_{odd} \Leftarrow \frac{\mathbf{w}_{base} - \beta \cdot \mathbf{v}}{\|\mathbf{w}_{base} - \beta \cdot \mathbf{v}\|}$$

$$\mathbf{w} \Leftarrow \frac{\mathbf{w}_{even} + \mathbf{w}_{odd}}{2}$$

// note: the base weight vector is only updated when feedback is received

end

The normalization of the even/odd weight vectors is applied (the 2-norm is used) so that the total power transmitted in even and odd time slots is equal. This normalization prevents the MS 229 from simply selecting the weight vector with the larger transmit power. Rather, the MS 229 must select the weight vector which delivers the maximum power to the mobile for the given transmit power, which is determined by the traffic and pilot channel gains $g_{traffic}$ and g_{pilot}.

In block 106, the weights determined in block 104 are applied to the pilot signal. In particular, $\mathbf{w}_{even}$ is applied to the pilot signal during even time slots and $\mathbf{w}_{odd}$ is applied to the pilot signal during odd time slots, using the multiplexers 68 and 70 as is shown in Figure 4. In addition, **w** is applied to the traffic signal during both even and odd slots. The pilot signal and the traffic signal, as modified

according to block 104, are transmitted from the antennae 52 and 54. More precisely, a sinusoidal carrier wave is generated for each of the antennae 52 and 54. Each of these carrier waves is modulated by the traffic and pilot signals (modulating signals) as modified according to block 104. Looked at from another perspective, the weight **w** adjusts the amplitude and phase of the plurality of radio carrier signals as those carrier signals are modulated by the traffic and pilot signals (modulating signals).

In block 116, which is shown as disjoint from blocks 100-106 for reasons that will be described below, the transmitter 50 receives a feedback bit transmitted by the MS 229. This feedback bit is based on the decision from the MS 229, which indicates which of the even or odd channels resulted in a greater received signal power and determines the weight updates for transmitter 50. In block 118, the transmitter determines whether the even weight yields greater power by checking the value of the feedback bit. (0 is arbitrarily taken to mean the even channel is better). If so, control passes to block 120, which sets equal to$\mathbf{w}_{even}$. (In broader terms, $\mathbf{w}_{base}$ is a function of $\mathbf{w}_{even}$ and $\mathbf{w}_{odd}$. In the preferred embodiment, the function is an 'or' type function but more complex functions of weight vectors, including combinations thereof, are conceivable.) Otherwise, control passes to block 122, which sets $\mathbf{w}_{base}$ equal to $\mathbf{w}_{odd}$. In block 124, the even and odd weights $\mathbf{w}_{even}$ and $\mathbf{w}_{odd}$ and the data weight **w** are updated based on the new $\mathbf{w}_{base}$. This is summarized as follows

when feedback received

if (feedback==0, indicating even channel is better)

$$\mathbf{w}_{base} \Leftarrow \frac{\mathbf{w}_{base} + \beta \cdot \mathbf{v}_{old}}{\left\| \mathbf{w}_{k,base} + \beta \cdot \mathbf{v}_{old} \right\|}$$

else

$$\mathbf{w}_{base} \Leftarrow \frac{\mathbf{w}_{base} - \beta \cdot \mathbf{v}_{old}}{\left\| \mathbf{w}_{k,base} - \beta \cdot \mathbf{v}_{old} \right\|}$$

end

$$\mathbf{w}_{even} \Leftarrow \frac{\mathbf{w}_{base} + \beta \cdot \mathbf{v}}{\left\| \mathbf{w}_{base} + \beta \cdot \mathbf{v} \right\|}$$

$$\mathbf{w}_{odd} \Leftarrow \frac{\mathbf{w}_{base} - \beta \cdot \mathbf{v}}{\left\| \mathbf{w}_{base} - \beta \cdot \mathbf{v} \right\|}$$

$$\mathbf{w} = \frac{\mathbf{w}_{even} + \mathbf{w}_{odd}}{2}$$

end

As mentioned above, block 116 (and related blocks) are shown as disjoint from blocks 100-106. This is because the processes represented by these two sets of blocks are independent of one another, as can be seen fromFigure 10, a timing diagram that shows a possible timeline for weight adjustment and channel measurement. Waveform 130 shows the timing of updates to $\mathbf{w}_{base}$, which are performed in blocks 120 and 122. Waveform 132 shows updates tov, which are performed in block 102. Waveforms 134 and 136 show updates to$\mathbf{w}_{even}$ and $\mathbf{w}_{odd}$, which are performed in blocks 104 and 124. Waveform 138 shows updates to the data channel weight vector **w**, which are performed in blocks 104 and 124.

As shown by waveform 132, the test vector **v** (step 102) is generated periodically and independently of feedback received from the MS 229. The updates to $\mathbf{w}_{even}$ and $\mathbf{w}_{odd}$ caused by a **v** are indicated by solid vertical lines in the Figure while the updates to $\mathbf{w}_{even}$ and $\mathbf{w}_{odd}$ caused by feedback received from the MS 229 are indicated by the dashed vertical lines in the Figure.

The parameter β is an algorithm constant which is to be selected to maximize performance. A large β allows the weight vector to adapt more quickly, but also introduces additional noise on the weight vector applied as a larger adjustment is made. For example, when the weights are settled near their optimal value, each weight is still constantly adjusted by $\pm\beta\mathbf{v}$. Also, β determines the size of the test perturbation applied to the weight vector, and hence will effect both the ability of the MS to correctly determine which test weight vector provides the larger power, and the amount of interference seen by other MS's. A larger β will cause the difference between the two test weight vectors to be larger, and hence it is more likely that this difference will exceed any noise contributions to the measurement by the receiver 80 or receiver 229. A larger β also causes more "splatter", wherein the antenna pilot transmission test weights are perturbed more from the base weights, which are adjusted towards an optimal value, and hence the odd/even pilots cause more interference to other MS's than the data weight. As an enhancement to the invention, it is possible to individually tune these two effects (i.e. the adaptation rate vs. weight noise tradeoff, and the noise immunity vs. splatter tradeoff) with a β_1 and a β_2, as is described later.

Figure 8 is a flow chart that outlines pertinent features of the operation of the receiver of Figure 5. In block 172 the even channel estimate is accumulated, which continues during the entire even time slot according to the decision of block 174. At the beginning of the odd time slot, the odd channel estimate is accumulated in block 176, which continues during the entire odd time slot according to the decision of block 178. The even/odd channel accumulations continue until it is determined by block 180 that the measurement period is complete. When the measurement period is determined to be completed, the feedback decision is calculated and the resultant bit stored for transmission at the appropriate time in block 182. The odd and even channel estimates are then cleared in block 190 and the process is started over for the new measurement period by returning to block 172. At the appropriate time, which is independent of the timing of the channel estimation procedure just described, the MS starts transmission of the feedback bit, which is shown in blocks 184, 186, and 188.

Figure 9 is a flow chart which outlines the pertinent features of the operation of the receiver of the preferred embodiment of Figure 6. In block 232 the sliding window data channel estimate is updated. The duration of the sliding window is shown as M slots, covering the duration of a measurement interval, as is preferred. The data channel estimate is applied to the preliminary symbol estimate in block 233. The state of the slot being processed is used in block 234 to determine the sign of the channel difference accumulation by adding the preliminary channel estimate in block 248 if it is an even slot, or subtracting the preliminary channel estimate in block 250 if it is an odd slot. Block 240 determines if the measurement interval is

complete, continuing the process by returning to block 232 if the interval is not complete. When the measurement period is determined to be completed by block 240, the feedback decision is calculated and the resultant bit stored for transmission at the appropriate time in block 238. The difference estimate is then cleared in block 236 and the process begins again by returning to block 232. At the appropriate time, which is independent of the timing of the channel estimation procedure just described, the MS 229 starts transmission of the feedback bit, which is shown in blocks 242, 244 and 246.

Figure 10 shows a time line of this process with certain parameters selected by way of example. The accumulations are of this example are over 12 time slots, the feedback bit is transmitted one time slot later, and the transmit weight update occurs as soon as the transmitter 50 receives it. In this case, the transmitter 50 updates the test perturbation vector **v** prior to receiving the update, so that the measurement of the new perturbation can begin. Since each update is fairly small, this mechanism allows for the maximization of the measurement time and the measurement of the new perturbation will be insignificantly modified by the overlap.

As previously described with reference to Figure 7, at the beginning of the each test period, the transmitter 50 determines a new perturbation vector **v** and applies it to the old $\mathbf{w}_{base}$. As soon as the feedback arrives this same new **v** would be applied to the new $\mathbf{w}_{base}$. This allows for maximizing the measurement interval without delaying the next test perturbation. Since the updates are relatively small,

the new perturbation will still give a valid measurement result even though it is applied to both the old and the new $\mathbf{w}_{base}$.

The invention may be implemented for "soft handoff" systems. Soft handoff in DS-CDMA is an operational mode wherein multiple BS's, each using a different spreading code, are transmitting the same data to a single MS. The reception at the mobile of these multiple signals benefits performance by providing diversity. According to an embodiment of the present invention, soft handoff may be implemented in the following manner. Each BS independently generates test weight vectors $\mathbf{w}_{odd}$ and $\mathbf{w}_{even}$ through the independent generation of test perturbation vectors $\mathbf{v}$. Each BS transmits the pilot and data as previously described. The MS makes a single decision based on the summation of the channel estimate powers for all BS's, and transmits a single feedback bit as previously described. Each BS independently implements the weight adaptation as previously described, without regard to the fact that it is in soft handoff. In summary, the MS uses the summation of all BS powers for the decision, and each BS behaves exactly as though it would even if not in soft handoff.

The application of the system described as this invention to the IS-95 standard and its derivative cdma2000 would most likely use N=64 chips (chip rate 1.2288MHz, giving 52.083us time multiplexing) and 1.25ms decision intervals. The length of the total even/odd accumulation would be implementation specific in the mobile, but probably 8N, 12N, 16N or 24N (1/2 of that for each of the even/odd accumulations). Another possible alternative would be 0.625ms decision intervals,

in which case the total even/odd accumulation would probably not exceed 12N. These timings fit well into the existing specification as 64 chips is the original symbol duration from IS-95 and still a common time unit, and 1.25ms is a "power control group", the timing upon which over the air closed loop power control updates take place, and is 1/16 of the most common frame length, 20ms. It will be appreciated that the present invention is not limited to any of the specific quantities mentioned above.

Some Alternate Embodiments

It will be appreciated that it is possible to use more than 2 time slots and a corresponding number of test weight vectors, which may be generated from a corresponding number of test perturbation vectors. Also, more than 1 bit could be used as feedback, corresponding to the greater number of time slots.

The generation of the test perturbation **v** can be done in many ways. Such generation should be pseudo-random so that over the long term the summation $\Sigma \mathbf{v}\mathbf{v}^H$ approaches an equi-diagonal matrix. The random elements can be generated as some probability distribution other than the binary one described (e.g. uniform distribution, gaussian distribution). Rather than pseudo-random generation, the vector could be generated by cycling through some fixed sequence. For example, the sequence

$$[1\ 0\ 0\ ..0]^T$$

$[j\ 0\ 0\ ..0]^T$

$[0\ 1\ 0\ ..0]^T$

$[0\ j\ 0\ ..0]^T$

...

could be selected, to scan through each weight independently. This satisfies the requirement on the long term summation of $\mathbf{v}\mathbf{v}^H$. This scheme, however, will typically result in slower operation.

The value of β could itself be adaptive. For fast varying channels, the value could be made larger, and for slower channels it could be made smaller. This would allow for some optimization of β with respect to channel variation rate.

The weight update can be further parameterized, allowing independent optimization of the adaptation rate vs. weight noise (β_1) and the measurability in noise vs. splatter (β_2) tradeoffs. β_1 is then applied to the update of $\mathbf{w}_{base}$, while β_2 is applied to the test weight vectors $\mathbf{w}_{odd}$ and $\mathbf{w}_{even}$. This is done as follows.

when feedback received or new test interval

    if (new test interval)

        $\mathbf{v}_{old} \Leftarrow \mathbf{v}$

        $\mathbf{v} \Leftarrow$ normalized test perturbation function

    end

    if (feedback received)

        if (feedback==0, indicating the even channel was better)

$$\mathbf{w}_{base} \Leftarrow \frac{\mathbf{w}_{base} + \beta_1 \mathbf{v}_{old}}{\left\|\mathbf{w}_{base} + \beta_1 \mathbf{v}_{old}\right\|}$$

        else

$$\mathbf{w}_{base} \Leftarrow \frac{\mathbf{w}_{base} - \beta_1 \mathbf{v}_{old}}{\left\|\mathbf{w}_{base} - \beta_1 \mathbf{v}_{old}\right\|}$$

        end

    end

$$\mathbf{w}_{even} \Leftarrow \frac{\mathbf{w}_{base} + \beta_2 \mathbf{v}}{\left\|\mathbf{w}_{base} + \beta_2 \mathbf{v}\right\|}$$

$$\mathbf{w}_{odd} \Leftarrow \frac{\mathbf{w}_{base} - \beta_2 \mathbf{v}}{\left\|\mathbf{w}_{base} - \beta_2 \mathbf{v}\right\|}$$

$$\mathbf{w} \Leftarrow \frac{\mathbf{w}_{even} + \mathbf{w}_{odd}}{2}$$

end

The parameters used in the time line of Figure 10 are exemplary only and are easily modified.

The exact nature of the feedback channel is not specified. It can be done as a puncturing onto the data channel as the power control bit is done in IS95, or onto the pilot channel as in cdma2000, or in some other manner.

The mobile can generate the channel estimations in a different manner than described.

The weight normalization described above is a total power normalization. Other normalizations can be chosen.

Alternate treatments of soft handoff can be used, though the previously described method is preferred. Rather than using only 1 feedback bit, a feedback bit may be included for each such basestation (or each such BS that has adaptive Tx antennae enabled) so that the mobile can send commands to each, or alternatively can time multiplex the feedback bits between the various BS's. The latter would result in a significant loss of performance to do the slower adaptation times.

The test weights $\mathbf{w}_{odd}$ and $\mathbf{w}_{even}$ are described as applied in separate time slots. It is possible to use other orthogonal modulation techniques such that they may be extracted. For example, rather than an odd and even time slot, odd and even orthogonal codes (perhaps from a set of walsh codes) could be used. This is not desirable for the preferred embodiment but may be desirable in other embodiments.

While the transmission medium is assumed to be the propagation of radio waves from transmitting antennae to a receiving antenna (or antennae), the invention is obviously extendable to the propagation of waves in other media. For example, the medium could be acoustic waves in a fluid or gas, from transmitting transducers to a receiving transducer (or transducers).

Conclusion

Numerous other variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such variations and modifications.